Surface Fluxes and Wind-Wave Interactions in Weak Wind Conditions

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LONG-TERM GOALS

We will investigate air-sea transfer of momentum, heat, and moisture under weak wind conditions. We will focus on effects of swell on turbulence transfer since swell phase speeds can be much faster than weak wind and swell can have significant impacts on air-sea interactions. Improved understanding of wave effects on marine atmospheric turbulent fluxes under weak wind conditions will be used to modify the existing bulk aerodynamic formula for numerical models.

OBJECTIVES

Our objectives for FY2006 are to analyze and compare sensible and latent heat fluxes obtained from the Pelican aircraft and the ASIT tower for the flight days collected during the CBLAST-Low main field campaign in 2003. This work was built upon our results that swell was found to significantly affect momentum transfer across the air-sea interface during the CBLAST-low main field campaign. The scientific objectives for analyzing the CBLAST-Low experiment data are to understand air-sea interactions under weak wind conditions by mainly focusing on vertical variations of air-sea interactions within wave boundary layers and marine atmospheric surface layers.

APPROACH

As reported last year, we concentrated on the days when the CIRPAS Pelican aircraft flew on the level runs along the east-west track over the ASIT tower and the wind direction was good for the tower sonic performance (6 days in total). As we found last year that although the momentum flux derived from the aircraft is flight-direction dependent, which was recently found to be a common problem for all aircraft flux measurements, the momentum flux comparison between the aircraft and tower was reasonable to within the uncertainty of random flux errors. During FY06, to increase the database for the comparison, we included five additional flights. During these five flights, the wind direction was bad for all the sonic anemometers on the ASIT tower but was not a problem for the aircraft measurement (31 July, the morning and afternoon of 14 August, and 18 and 28 August, 2003). We applied the Ogive method for calculation of all turbulent fluxes for the total of 11 flights. The comparison between the aircraft and tower fluxes at four observation heights is done as a function of the atmospheric stability (z/L, where z and L are the observation height and the Ohbukhov length at the lowest observation height on the ASIT tower) and wave age (cp/ws, where cp and ws are the peak wave phase speed measured at the tower and wind speed at the top observation level of the ASIT tower).

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WORK COMPLETED

We have analyzed momentum, and sensible and latent heat fluxes using the ASIT tower data during the 6 Pelican flights when the wind direction was good for the tower sonics anemometers, and using the Pelican aircraft data for 11 flights. We investigated influences of swell on these fluxes as functions of the wave age and atmospheric stability.

RESULTS

1) Influences of swell on momentum flux

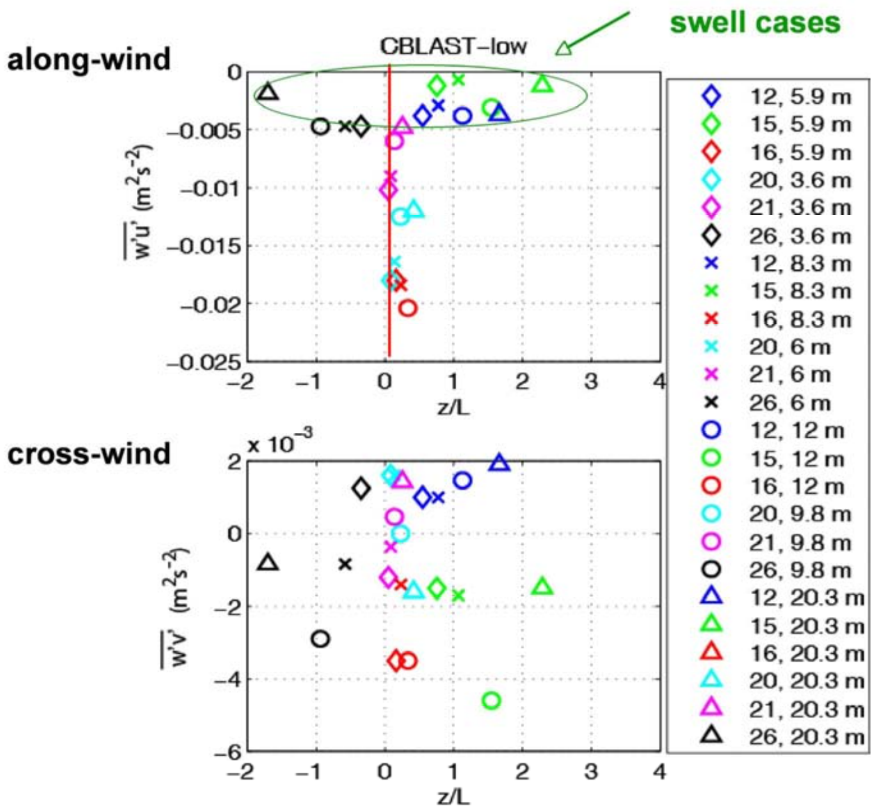

Figure 1: Along-wind (top) and cross-wind (bottom) momentum as functions of the atmospheric stability (z/L) at the four observation heights on the ASIT Towers during the six Pelican flight days. Each symbol represents a flight day in August 2003 and the observation height. The plot demonstrates that the downward (negative) momentum fluxes were significantly smaller for swell cases than for non-swell cases.

Although the momentum flux calculated using the Pelican aircraft data is flight-direction dependent, the aircraft momentum flux compared well with the tower momentum flux (not shown here). The aircraft momentum fluxes for the flight days when the wind direction was not good for the sonic anemometers are reasonable compared to the other flight days. Overall the downward momentum flux was reduced in the existence of swell under both stable (Figure 1) and unstable (based on the aircraft flux comparison between swell and non-swell days, which is not shown here) conditions.

2) Influences of swell on sensible and latent heat fluxes

We found that swell has significant effects on sensible and latent heat fluxes as well as momentum flux. Based on our limited flight days, we found that both sensible and latent heat fluxes were reduced under both stable (Figure 2) and unstable (based on the aircraft flux comparison between swell and non-swell days, which is not shown here) conditions. The reduction of all the turbulent fluxes could be associated with the weak shear instability in generation of turbulence at the air-sea interface.

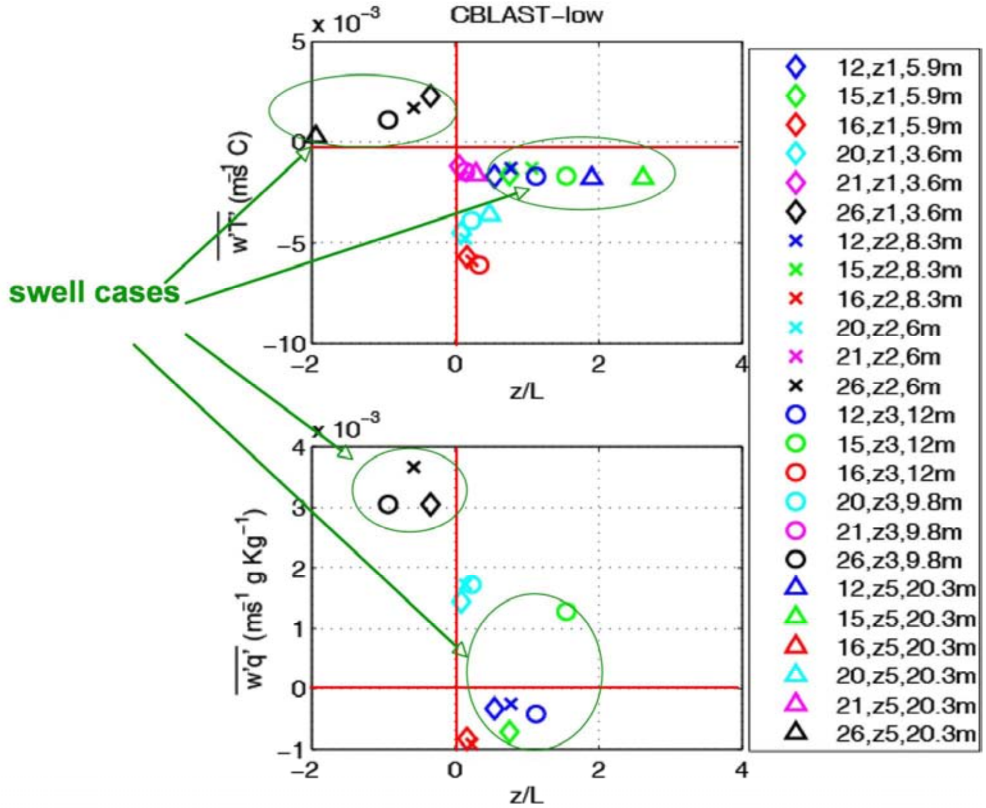

Figure 2. Heat (top) and moisture (bottom) fluxes as functions of the atmospheric stability (z/L). Here all the fluxes were calcuated using the ASIT tower data. Each symbol represents the observation day in August, 2003 and the observation height on the ASIT tower. The plot demonstrates that both sensible and latent heat fluxes are small due to the reductions of shear-generated turbulence.

IMPACT/APPLICATIONS

In the low-wind regime over oceans, swell can travel much faster than wind. Under this situation, the influence of swell on air-sea interactions is evident in all turbulent fluxes across the air-sea interface. If wind is strong, oceanic waves including swell and short waves act as friction to reduce the air flow. Swell can transport energy into the atmosphere, and reduce shear generated turbulence. However, even under weak wind, the momentum transport from the sea to the air, i.e. the positive momentum transfer, due to the fast moving swell is rarely observed due to interactions between coexisting slow moving short oceanic waves and the air flow above the ocean surface.

It is well known that the momentum exchange coefficient increases with wind speed, except for wind is less than about 4 m/s. Although random flux errors and self-correlations under weak wind conditions contribute part of the observation that the exchange coefficient for momentum increases with deceasing wind speed under 4 m/s, some real physical processes also contribute to the behavior of the exchange coefficient under weak winds (Mahrt et al. 2003; and Klipp and Mahrt 2004).

Our data analysis results imply that although swell reduces turbulent fluxes at the air sea interface, it also reduces the calculated atmospheric stability (z/L). As a result, turbulence fluxes under swell conditions are actually higher than predicted turbulent fluxes based on the relationship between z/L and turbulent fluxes developed over land. With higher turbulent fluxes and weak wind, the calculated exchange coefficient will be higher for swell cases than for non-swell cases. Therefore, the increase of the exchange coefficient with decreasing wind speed observed in the literature could be partly due to contributions of swell under weak wind conditions. To generalize the above explanation, more data with simultaneous measurements across the air-sea interface are needed.

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